Autonomous Photovoltaic Panels Cleaning System

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Mechatronics – ME5643
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Abstract:

Photovoltaic (PV) panels convert sunlight into electricity and this method is a form of nonrenewable energy. However, one problem with PV panels is that a buildup of dirt over time can significantly reduce the efficiency of these panels, by as much as 30%. The design that was decided upon by our group consists of a mechanism, which behaves much in the way of a wiper blade on a car, to clean the solar panel. This “wiper blade” is fitted with an electrostatic cloth, attached to a servo motor and interfaced with and operated by the Basic Stamp 2 (BS2). In addition to this, a dust detecting system is used to determine when it is best to clean the panels. This means that the energy is not wasted by always cleaning the panels or by having the efficiency reduced as a result of dirt. Finally an emergency system is equipped to provide an automatic shut off in the form of a button and a digital thermometer.

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Project Need and Outline:

The purpose of this project was to develop a means of cleaning photovoltaic panels (PV panels) or solar panels autonomously in order to maximize the efficiency and energy output from these panels. Solar panels, being used for a large commercial application such as solar farms or on a smaller scale as in the case of residential application, will inevitably get dirty simply due to the environment in which it exists. The U.S. Department of Energy figures have shown that panel efficiency may be reduced by up to 7% from airborne dust particles alone. Adding in other factors such as falling leaves and water streaking, the efficiency of these panels can be further reduced to as much as 15 – 30%. Some studies have linked this reduction in output to as much as $10,000 of lost value. In the case of a commercial installation, this would be a significantly higher cost.

For this project, we narrowed our focus for more of a smaller scale, as in the case of residential use. There were several considerations taken into account when designing this system. Firstly, in the case of residential use, solar panels are usually placed on the roof to receive the maximum amount of sunlight. As a result of this, cleaning these solar panels would result in the homeowner climbing up onto the roof to clean the panels, which can be very hazardous. The other option would be to hire a company to do it for them. However, considering a typical home with 40 panels, a rate of $5 to $10 and cleaning every three months would result in an annual cost of $800 to $1600. Furthermore, if we then estimate that the panels will remain clean enough to maximize the output for 4 days after they are cleaned, then the remaining 86 days until the next cleaning, the solar panels will be operating at a reduced efficiency. This essentially means that the solar panels will only be operating at its maximum efficiency for about 4% of the time. As a result of this, it only made sense that the system being designed should be autonomous to prevent having to climb up onto the roof and save money by allowing for the solar panels to be cleaned often.

Another factor taken into consideration was that solar panels tend to be placed in areas where there is a lot of sunshine and as a consequence, very little rain. Therefore, not only would it be unwise to solely depend upon rainfall to clean the panels, but water usage, for self-cleaning, in these areas may be limited as well. For this reason, an electrostatic cloth was used instead.

Also, there needed to be a way of determining when to clean the solar panel since having it cleaned all the time would be equally a waste of energy. Additionally, we could not solely depend on there being a reduction of voltage from the solar panels as a method of determining when it should be cleaned since a cloudy day would also result in a reduction of voltage.

Finally, in the event of an emergency or system malfunction, there needed to be a way of turning off the system. Therefore a button was interfaced with the BS2 to provide a means of shutting off the system quickly. Also, as the servo motor has an operating range between -10°C to 50°C, a digital thermometer was also used to determine when the temperature in the environment was outside of this range.

Project Motivation:

This project really appealed with everyone in the group as we were all interested in working on something "green." One of the members in the group is currently participating in the Solar Decathlon competition. This competition seeks to a build an aesthetically pleasing, affordable and appealing home, in which everything in the house (appliances, heating/cooling, electronics, etc.) is entirely powered by solar panels. In addition to this, all the members in our group were affected by the recent Hurricane Sandy. This has spurred our interest into going more "green." Finally, the rovers placed on Mars are dependent on solar power; however, sand storms on Mars kicks up the dust onto the solar panel, reducing the efficiency of the panels.

Background Theory:

Photovoltaic Cells:

Photovoltaic panels convert sunlight into electricity. The word photovoltaic is derived from *photo*, the Greek word for light and *volt*, relating to electricity pioneer Alessandro Volta. They have been around for quite some time now and are very noticeable in calculators. PV cells are made of a material know as semiconductors, the most common being used is silicon. Essentially, when the light strikes the cell, some of this is absorbed within the semiconductor material. Energy absorbed from the light and then transferred to the semiconductor, knocks the electrons loose, allowing them to flow freely. This flow of electrons is a current. Since PV cells can produce a maximum of 0.5V, placing these cells in-series or in-parallel can increase the total current/voltage. When building a solar panel, an antireflective coating is also applied to silicon to reduce losses from photons bouncing away. The solar panels are then covered with a glass plate to protect them from the elements. However, this glass plate is susceptible to dust from the surrounding environment. Once this glass plate becomes dirty, less light will penetrate through, thus reducing the efficiency of the solar panels.

RC Circuit:

A simple and effective way to retrieve analog values into the BS2 is by using an "RC circuit". An RC circuit is done by a series network consisting of a resistor and a capacitor. The RC circuit has a value, called τ, which represents its time constant.

$$\tau = RC$$

Tau, τ, is the time taken by the system response to reach 63.2% of its steady-state value. In our case the variable element is the photoresistor which outputs different values of resistance with respect to the lighting conditions.

BS2 is interfaced to the circuit and it is able to detect if the capacitor is charged or discharged to or from a specified voltage level. BS2 is able to monitor (from the command RCTIME) the time that the capacitor takes to charge. By linking the BS2's pin to the RC circuit, BS2 can detect when the 1.4V threshold is overcome (this threshold is considered by the microcontroller as the transition point between HIGH and LOW). When this threshold is overcome the BS2 saves and stores this value. This value is called t_f which is a multiple of τ.

$$t_f = -\tau * \ln\left(\frac{1.4\,V}{V_s}\right)$$

As the R value changes, the outcome of the RCTIME command also changes; this is the key point of our project. In dark conditions (for our project, when the glass is dirty), the resistance is very large (approximately in MΩ), while in bright conditions (when the glass is clean), the resistance is much smaller (approximately 20KΩ). By comparing the difference of the two RC circuits returned by the RCTIME command, a threshold value can be set to determine when the solar panel needs to be cleaned.

Hardware:

BASIC Stamp 2:

BASIC Stamp 2 is used as the microcontroller to control the entire system (See Appendix, Figure 2). BS2 commands the motion of the Servo Motor which, thanks to "wiper blade" mechanism, can clean the glass on the photoresistor.

In addition, our microcontroller measures two constants, τ, from two distinct RC circuits, both of them which uses a photoresistor. BS2 then checks if the difference between the two τ values is higher than a predetermined threshold and then activates the two other "wiper blades" if the threshold is overcome. To be precise, the BS2 doesn't measure the τ constant; instead, it measures its multiple, t_f. In the duration of this paper, we refer to what the BS2 measures as the τ constant.

Next, BS2 continuously check the status of a NO active high button connection to allow the user an instantaneous shut off of the system in the event of an emergency or system malfunction.

Last but not least, BS2 checks for the temperature of the system before activating the servo motors. This is because every piece of hardware in the system has a certain range of working temperature.

Photoresistors:

Photoresistors are built in an RC circuit. By using this sensor we can perform a cleaning of the solar panel without encoding any reference value in the PB2 code. The two photoresistors needs to be very sensitive because the difference between the τ values is due to some dust on the glass which covers the photoresistors. So, we have chosen the

VT935G-B which has a sufficient sensitivity (0.9 γ). This photoresistor can be seen in Appendix, Figure 3.

Digital Thermometer:

A digital thermometer, DS1260 (Appendix, Figure 4), is also used. This thermometer is chosen because it has a very large operating temperature range (-55 to 125°C). Each device which is used in our apparatus has an operating temperature range which is contained in the DS1260's one. This means that by continuously monitoring the temperature of the system we can realize if each device is well fitted in its temperature range. In addition, it can be simply interfaced to the BS2. It has a power requirement which perfectly matches the voltage provides by our system (6 VDC).

Parallax Continuous Rotation Servo & Standard Servo:

The Parallax Continuous Rotation Servo (Appendix, Figure 5) is chosen to move the "blades" which cleans one glass and the solar panel. This actuator is able to produce enough torque to move the weight of the wooden stick and of the Swiffer© towel. In addition, the brush will generate friction while it is cleaning, but the torque of the Parallax Continuous Rotation Servo (0.268 N-m @ 6 VDC) can face that by showing a smooth motion. The same considerations are also applicable at the Parallax Standard Servo (Appendix, Figure 6) which has the aim to clean the other glass that covers the photoresistor ("always clean glass"). This second motor is preferable because it shows a better controlled position; this means that it always stops at the preconfigured angles. The Continuous Rotation Servo on the other hand, shows a little deviation with respect to its preconfigured position. This issue pushes us to put two pieces of wood at the end of run of the "wiper blade" driven by the two Continuous Servos. This can properly control the ending point of their run.

Solar Panel:

The Parallax Solar Panel (Appendix, Figure 7) was chosen for our apparatus. The reason which led us to choose this panel was that it has a simple interface to the Bread Board as it came pre-soldered with the positive and negative wires attached to it. In addition, it outputs 9V @ 1W which is a good enough amount of voltage for the presentation purposes.

Project Description:

Dust Detecting System:

The dust detecting system consists of two pieces of transparent glass panels, one standard servo motor, two continuous servo motors, and two photoresistors connected in resistor-capacitor (RC) circuits. Each servo motor is attached with one piece of wooden stick that is wrapped by an electrostatic cloth and the servo motors are used to clean the glass panel by rotating 90 degrees clockwise and then 90 degrees counter-clockwise, mimicking the motion of a wiper blade. Each photoresistor is placed under a glass panel and is used detect the light. The glass panel attached with standard servo motor is cleaned every 1 minute (this time is kept short for purposes of the presentation) and done to ensure that the glass is kept clean at all times. As a result of this, the resistance of this photoresistor does not vary a significant amount and the value returned from the RCTIME command will not vary a great deal either. Over time, the other glass panel, attached with continuous servo motor, will get dirty from the airborne dust particles, etc., thus causing the photoresistor under this panel to detect less light. Because of this, the resistance will increase on the photoresistor and the value returned from the RCTIME command will be significantly greater than that of the constantly cleaned glass. When the difference between the charging time of the dirty panel and the charging time of the clean panel is greater than the predetermined threshold (350), the dirty glass panel is cleaned. However, before cleaning, the program will wait for a period of time and then check again that this threshold is still overcome. This is to prevent a scenario where a cloud is passing by and blocking one of the photoresistors, thus causing one of the photoresistors to register as "dirty."

Autonomous Solar Panel Cleaning System:

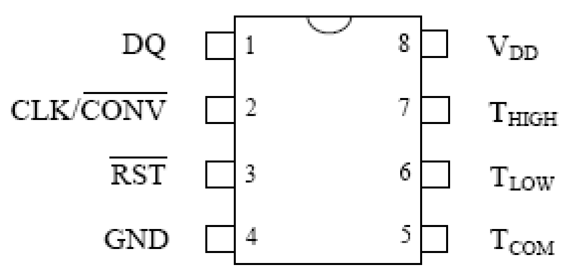
The Autonomous Solar Panel Cleaning System consists of one solar panel with a cleaning mechanism similar to that which is used for the glass panels covering the photoresistors. Since the solar panel and the two pieces of glass panels are placed in the same environment, when the glass panel that is not being cleaned frequently gets dirty over time, so will the solar panel also get dirty. Once the dust detecting system determines that the 2nd glass panel needs to be clean (when the difference between the RCTIME of the dirty panel and the RCTIME of the clean panel is greater than the threshold of 350), it activates for the solar panel to be cleaned simultaneously.

Emergency System:

In order to protect the entire system, we designed two approaches that can be utilized to automatically shut down the system. One is an emergency button, while the other one is a temperature control. The emergency button is for stopping the entire system in the event of any emergency malfunctions; when the button is pressed, the entire system will stop and a warning will be displayed on the screen to notify the user that they must manually restart the system. Since the servo motors can only operate in the temperature range of 0°C to +50°C, a digital thermometer is used to detect the environmental temperature. When the environmental temperature is outside of this range, the servo motors stop working and the system is turned off.

System Operation:

All parts that are discussed above, photoresistors (in RC Circuit), continuous and standard servo motors and button are all interfaced with the BS2 as shown in Figure 8 (Appendix) below. Pins 12, 13 and 15 connect the servo motors, which are used as the cleaning mechanism. The BS2 is powered by 4 AA batteries, which provide 6V. Pins 0 and 11 are connected to the two photoresistors. Through these pins and with the RCTIME command, the value t_f, explained above, is returned. Additionally, the button is interface with the BS2 in a NO active high connection at Pin 1. Finally, pins 8, 9 and 10 of the BS2 are connected to the digital thermometer at Pins 1, 2 and 3. The image below shows the correct configuration on how to properly interface the DS1620 digital thermometer with the BS2.



DS1620 8-Pin DIP (300-mil)

To run the system, simply connect a computer to the BS2 via a USB cable and run the program. Once the programming is running, the display window will show the operating temperature and inform of the different possible scenarios. Figures 9 – 12 show all different scenarios that can be displayed in the DEBUG window of the program.

Project Cost:

Item No.	Item Description	Unit Price ($)	Quantity	Total Price ($)
1	Board of Education with Basic Stamp 2	99.99	1	99.99
2	RadioShack® Universal Solderless Breadboard	24.99	1	24.99
3	Solar Panel	9.99	1	9.99
4	Photoresistor	1.99	2	3.98
5	Capacitor (0.1 μF)	0.15	3	0.45
6	Resistor	0.15	5	0.75
7	Wire	0.05	23	1.15
8	Servo Motor	12.99	3	38.97
9	Digital Thermometer (DS1620)	5.99	1	5.99
10	Button	0.50	1	0.50
11	Screw	0.50	1	0.50
12	Wooden Stick	1.67	1	1.67
13	Wooden Wedge	1.57	1	1.57
14	Glue	5.97	1	5.97
15	Batteries	0.50	4	2.00
		Total Cost ($):		**198.47**

Discussions:

Advantages:

There are several advantages to this project. These advantages were listed and explained above, but to summarize, they were:

1. Autonomous self-cleaning mechanism that can be attached to solar panels and operated without human operation.
2. Project will maximize the efficiency of the solar panels, resulting in these panels to pay-off for themselves earlier.
3. Easy to construct, low cost and low maintenance.
4. The dust detecting system allows for the system to be cleaned only when necessary, above a certain threshold. The reduced voltage from cloudy day wouldn't "fool" the system into thinking that it needs to be cleaned.

Disadvantages:

There are some disadvantages we've noticed while working on this project. Listed below are these disadvantages:

1. "Wiper Blade" which consists of an electrostatic cloth would need to be changed.
2. Needs to be scaled for a larger project (ex: increase the torque of the motor).
3. System is not powered by the photovoltaic cells; instead it is battery powered.
4. System used 2 continuous servo motors; standard servo motors are better.

Future Work:

Relating to the disadvantages listed above, there are some changes our group would make in the future. For example, we would need to design a better "wiper blade" so that changing it is required much less often. The other solution would include allowing it to be changed much more easily, such as a slide on/slide off system. Also, by using a regulator, such as the LM7805, one can interface the 9V solar panel with the BS2 to power the system. Finally, our group noticed that working with the continuous servo motor was not ideal since there is no way to automatically bring it back to the starting position. We've noticed that the continuous servo motor sometimes is a bit off, not always going back to the initial position. However, the standard servo motor works much better and the project should therefore be changed to include 3 standard servo motors instead.

Appendix:

Program Code (BASIC Stamp Editor v2.5):

The BS2 was programmed using BASIC Stamp Editor Version 2.5. The full code is listed below with comments highlighted by the green color. The code begins by stating that the stamp mode will be BS2, the PBASIC language is 2.5 and then goes on to declare the variables. The surrounding temperature is then checked since the servo motor has an operating temperature between 0°C to 50°C. If the temperature is within this range, glass 1 is cleaned; however, if the temperature is outside of this range, the servo motors are driven low and the program is terminated. The RCTIME command is then used to determine whether the 2nd photoresistor detects less light than the 1st (cleaned) photoresistor, thus indicating that the glass and solar panel are dirty. If this happens to be the case, both the 2nd glass and solar panel are cleaned and there is a 1 minute pause before restarting the program again. If the RCTIME values indicated that the 2nd glass was not dirty enough to warrant the need for the solar panel to be cleaned, the program was pause for 1 minute and then rerun from the beginning.

```
' {$STAMP BS2}
' {$PBASIC 2.5}

'List the Variables
tau_clean VAR Word
tau_dirty VAR Word
counter VAR Byte
btn1 VAR Byte
x VAR Byte
y VAR Word
degC VAR Byte
rem VAR Byte

DO
DO
DO

LOW 12
LOW 13
LOW 15

'Check the temperature
HIGH 8
SHIFTOUT 10, 9, LSBFIRST, [238]
LOW 8
HIGH 8
SHIFTOUT 10, 9, LSBFIRST, [170]
SHIFTIN 10, 9, LSBPRE, [x]
LOW 8

degC = x / 2
'Display the temperature
DEBUG CLS, "Operating Temperature = ", DEC2 degC

'Terminate program if temperature outside of operating range
IF degC > 50 THEN
 DEBUG CR, "Warning: Operating Temperature is Too High!"
 PAUSE 2000
 GOTO Finish
ELSEIF degC < 1 THEN
 DEBUG CR, "Warning: Operating Temperature is Too Low!"
 PAUSE 2000
 GOTO Finish
ENDIF

'Clean Glass 1 (every min.)
```

```
'Standard Servo-motor - Photoresistor 1 (Counter Clockwise)
FOR counter = 1 TO 20
PULSOUT 12, 680
BUTTON 1, 1, 255, 0, btn1, 1, Finish:
PAUSE 100
NEXT
'Standard Servo-motor - Photoresistor 1 (Clockwise)
FOR counter = 1 TO 20
PULSOUT 12, 350
BUTTON 1, 1, 255, 0, btn1, 1, Finish:
PAUSE 100
NEXT

'RCTIME - 2 Photoresistors
HIGH 0
HIGH 11
PAUSE 5
RCTIME 0, 1, tau_clean
RCTIME 11, 1, tau_dirty

'Compare RCTIME to determine if panel needs cleaning
IF ABS(tau_clean - tau_dirty) > 350 THEN
 DEBUG CR, "Solar Panel is Dirty!"
 PAUSE 5000
 GOTO Check
ENDIF

'Pause for 1 min. and rerun program from start
FOR counter = 1 TO 240
BUTTON 1, 1, 255, 0, btn1, 1, Finish:
PAUSE 250
NEXT

LOOP

Check:
FOR counter = 1 TO 240
BUTTON 1, 1, 255, 0, btn1, 1, Finish:
PAUSE 250
NEXT
IF ABS(tau_clean - tau_dirty) > 350 THEN
 DEBUG CR, "Cleaning Solar Panel!"
 PAUSE 5000
 GOTO Clean
ENDIF
```

```
LOOP

'If above threshold, clean the glass & solar panel
Clean:
'Rotate Clockwise
'Continuous Servo-motor - Photoresistor (Dirty) & Photovoltaic Cell
FOR counter = 1 TO 5
PULSOUT 13, 550 'Photoresistor 2 (Dirty)
BUTTON 1, 1, 255, 0, btn1, 1, Finish:
PAUSE 100
NEXT
FOR counter = 1 TO 7
PULSOUT 15, 450 'Photovoltaic Cell
BUTTON 1, 1, 255, 0, btn1, 1, Finish:
PAUSE 100
NEXT
PAUSE 250
'Rotate Counter-Clockwise
'Continuous Servo-motor - Photoresistor (Dirty) & Photovoltaic Cell
FOR counter = 1 TO 6
PULSOUT 13, 950 'Photoresistor 2 (Dirty)
BUTTON 1, 1, 255, 0, btn1, 1, Finish:
PAUSE 100
NEXT
FOR counter = 1 TO 7
PULSOUT 15, 930 'Photovoltaic Cell
BUTTON 1, 1, 255, 0, btn1, 1, Finish:
PAUSE 100
NEXT

FOR counter = 1 TO 240
BUTTON 1, 1, 255, 0, btn1, 1, Finish:
PAUSE 250
NEXT

LOOP

'Terminate program if button is pressed or outside operating temp.
Finish:
LOW 12
LOW 13
LOW 15
DEBUG CLS, "PLEASE CHECK SYSTEM AND RESTART MANUALY!"
```

Figures:

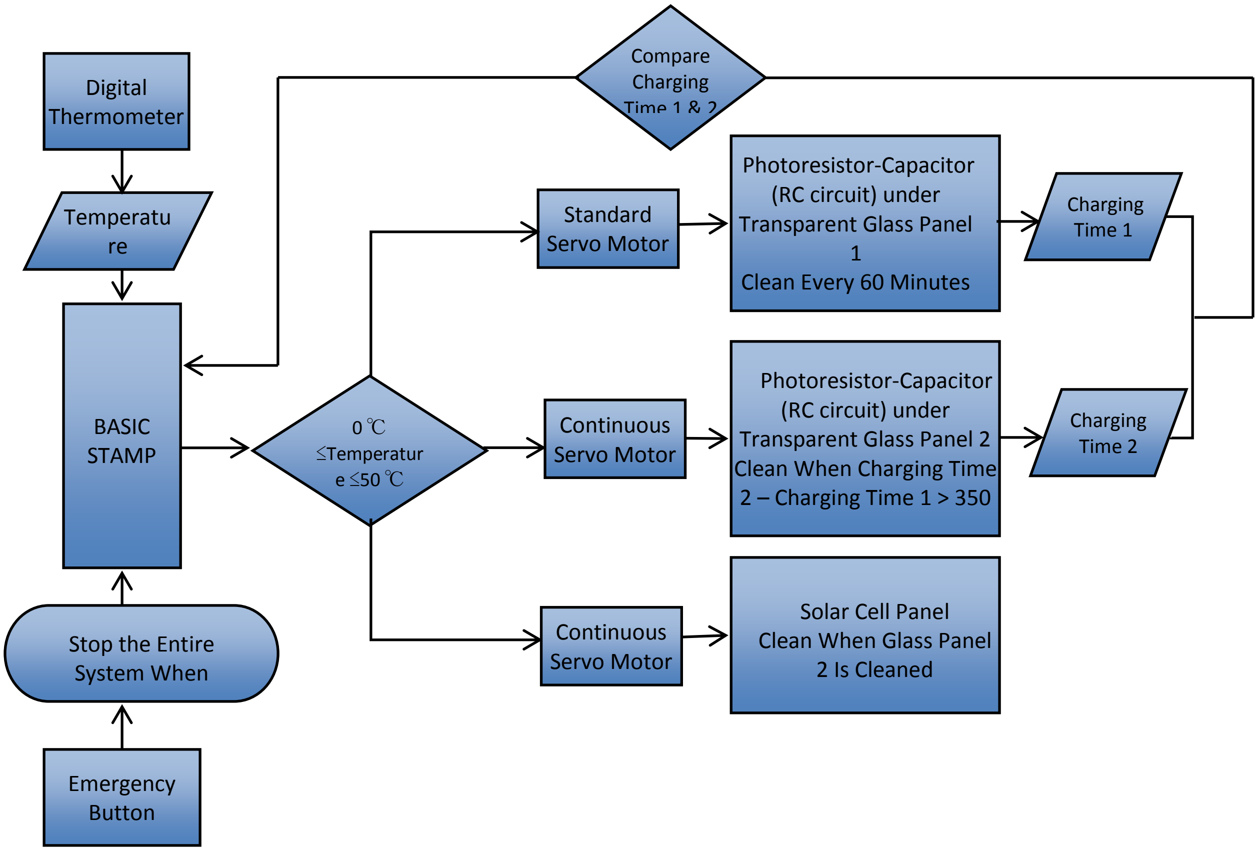


Figure 1: Operational Flow Chart

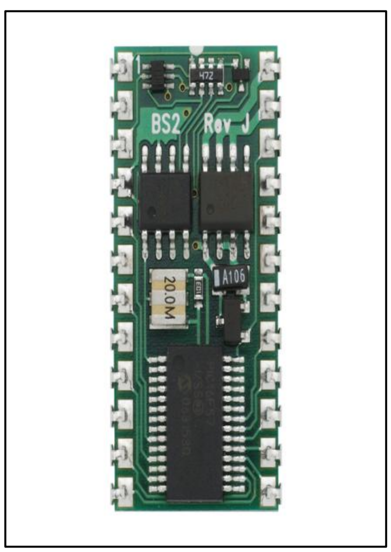


Figure 2: Basic Stamp 2 Microcontroller

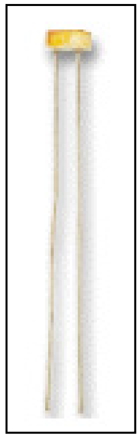


Figure 3: Photoresistor, VT935G-B

Figure 4: Digital Thermometer, DS1620

Figure 5: Parallax Continuous Rotation Servo Motor

Figure 6: Parallax Standard Rotation Servo Motor

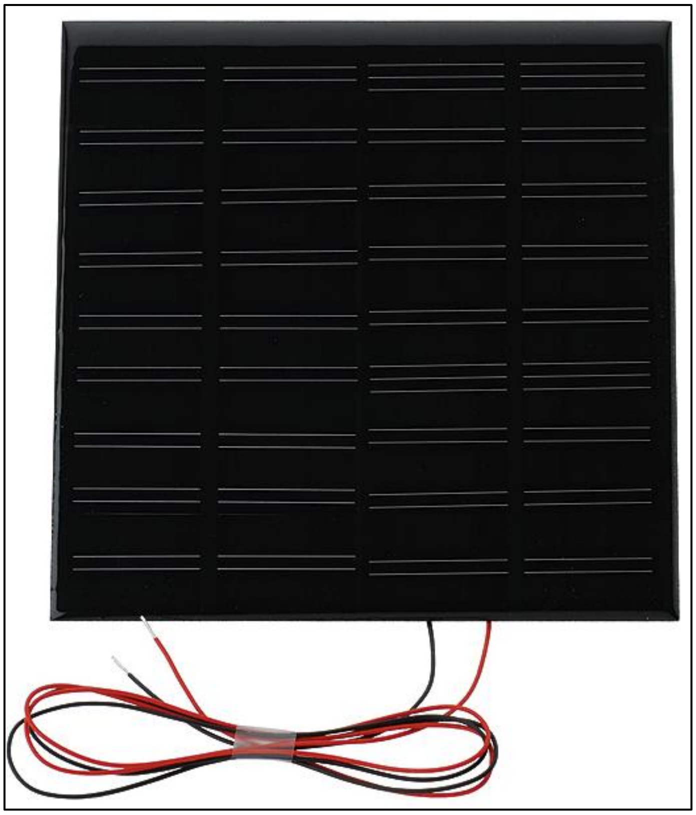


Figure 7: Parallax Solar Panel

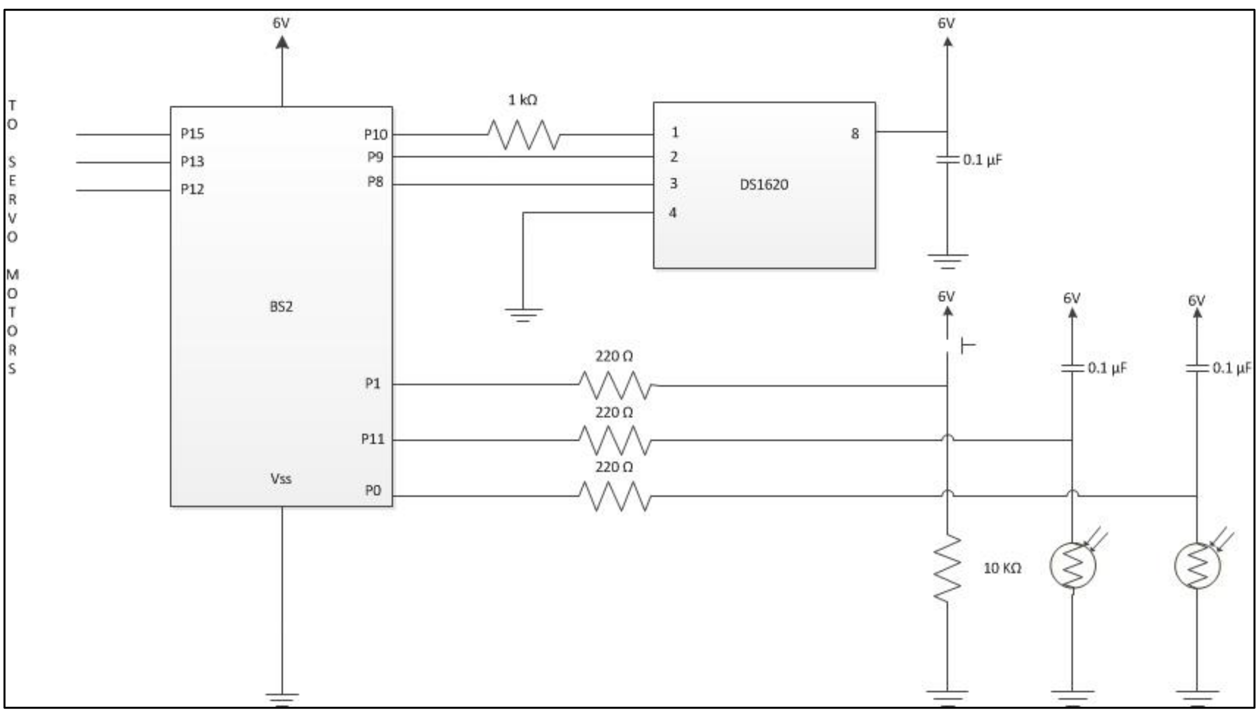


Figure 8: Circuit Connections

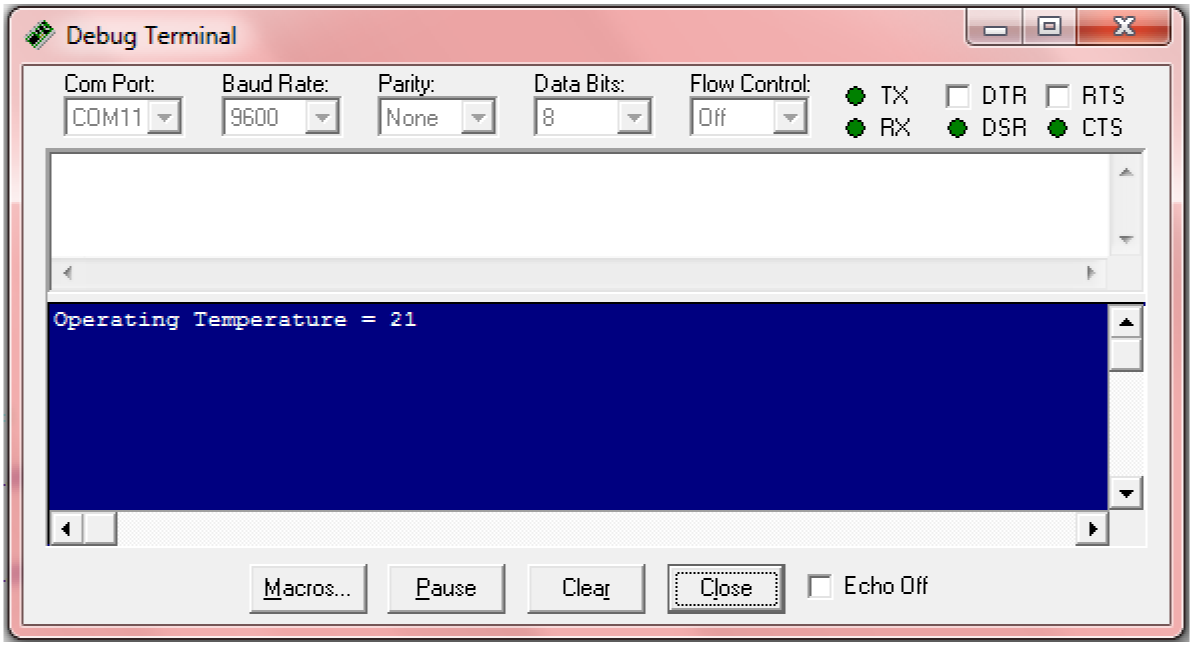


Figure 9: DEBUG - Operating Temperature

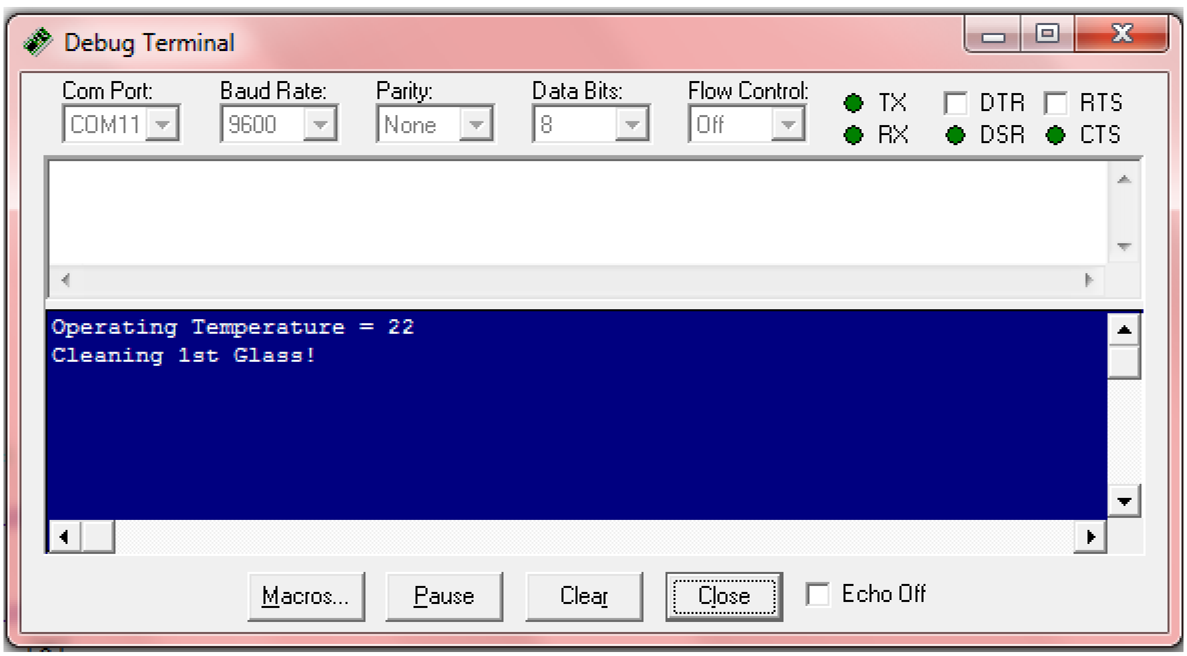


Figure 10: DEBUG - Cleaning 1st Glass

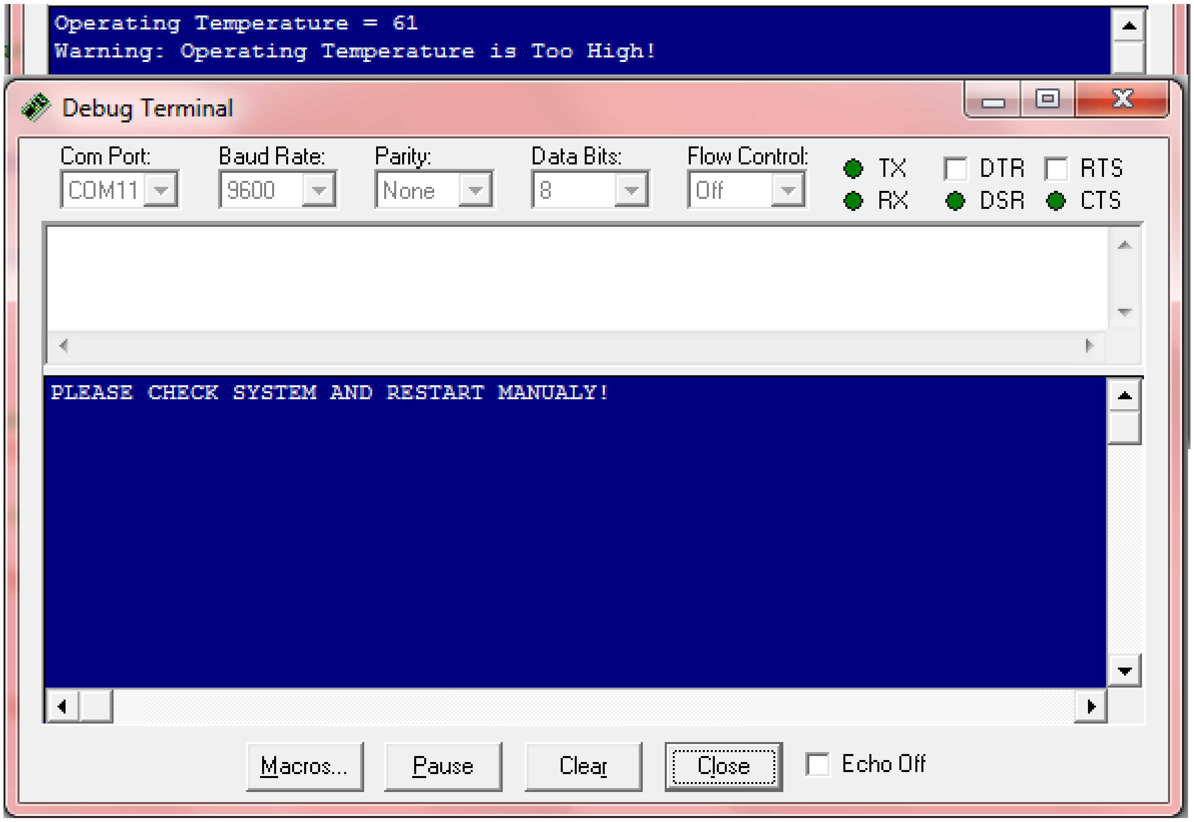


Figure 11: DEBUG – Operating Temperature too Hot (Cold)

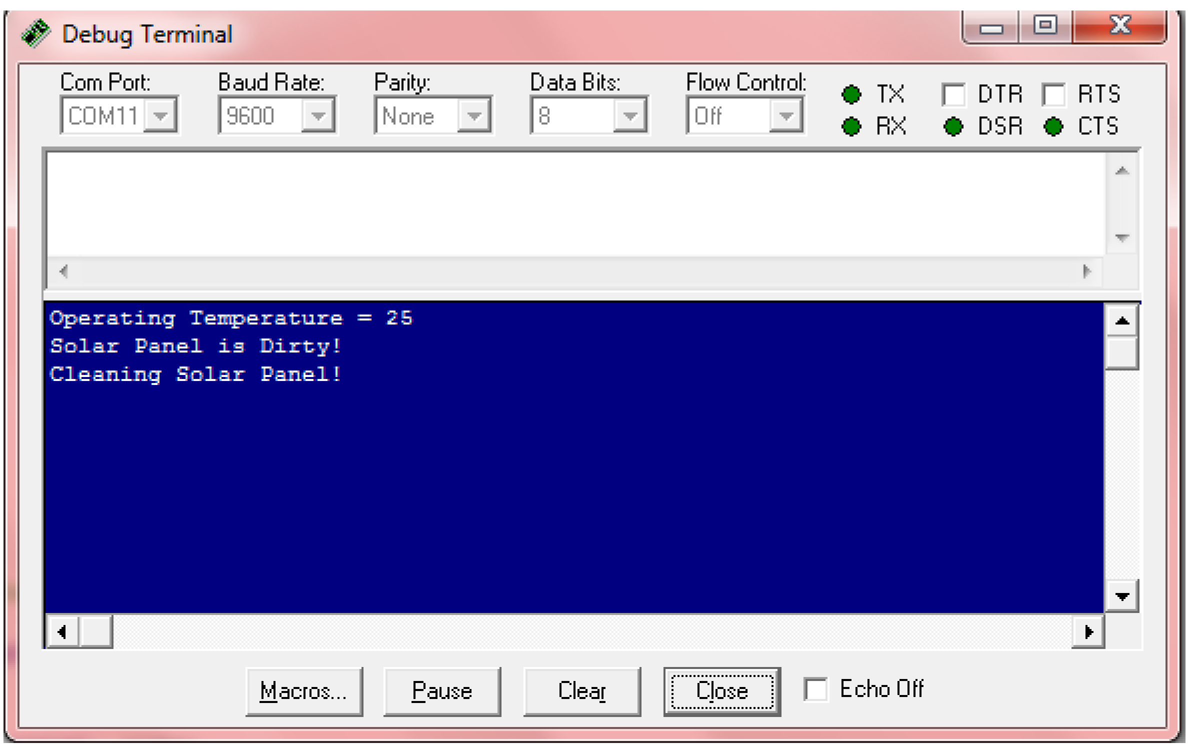


Figure 12: DEBUG - Cleaning Solar Panel!

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